ABATING STREAM POLLUTION BY RECOVERING WASTE OIL FROM STEEL ROLLING MILLS

BY B. P. MARTINEZ

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ABATING STREAM POLLUTION BY RECOVERING WASTE OIL FROM STEEL ROLLING MILLS[1/]

by

B. P. Martinez[2/]

SUMMARY

This report presents the results of a research and development program in recovering waste-rolling oils conducted by the Bethlehem Steel Co., before 1954 at its Sparrows Point plant, Sparrow Point, Md., with the cooperation of the Bureau of Mines, U. S. Department of the Interior, College Park, Md. The objective of the program was twofold: First, to recover oil for reuse in the plant; and second, to stop pollution, by oil, of the stream and harbor areas in the immediate vicinity of the plant. The sequence of the investigations was laboratory and pilot plant studies on sedimentation, simple aeration, and flotation for the separation of oil and water; and construction of a production unit using standard flotation equipment. This work was only preliminary for the Bethlehem Steel Co. and it has continued research on this problem. Recent progress indicates that new, improved processes will soon replace the flotation units described in this report.

The first efforts to separate oil and water by simple sedimentation were unsuccessful. To establish the cause of this failure, microscope examinations and measurements were made on cold-reduction rolling mill cooling-water effluents containing oil in suspension. It was discovered that an average oil globule, held in suspension, was only 0.0001 inch in diameter and would not coagulate with other globules for normal sedimentation at room temperature. The next step in the sequence of studies was to coagulate the oil suspension by simple aeration with air under slight pressure. The aeration methods studied were effective in removing up to 68 percent of the total oil but were approaching flotation in principle. The final investigation of the series was flotation of the oil in conventional laboratory-size flotation cells. The small-bubble method, without reagents, floated up to 89 percent of the total oil held in suspension and was the process selected for pilot-plant development.

Based on the efficiency of oil salvage shown with an 81-gallon-capacity flotation machine, a production plant using standard flotation equipment was

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designed and constructed to treat 6,000 g.p.m. of effluent cooling water containing about 500 to 700 p.p.m. of the colloidal-size oil held in suspension. This plant floated nearly 65 percent of the total waste-rolling-mill oil, along with dirt and steel particles, from the water discharged from the cold-reducing rolling mills. The floated oil sludge, removed from the liquid surface in the cells by skimming and a final lagoon also having a skimmer, was pumped to an oil-refining plant operated by Palm Oil Recovery, Inc. The refined oil was returned to the steel plant for reuse in the rolling mills.

The basic objectives of the waste-oil salvage program were realized through the use of standard flotation equipment and the skills of Palm Oil Recovery, Inc. The cost of rolling-mill oil per ton of steel was materially reduced. The flotation plant was a profitable operation which paid for itself the first few years of use. With this, the stream-pollution problem, brought about by a discharge of waste-rolling-mill oil into the local streams and harbor areas, was greatly reduced.

ACKNOWLEDGMENTS

The assistance of W. C. Lorenz, chemical engineer in the Bureau of Mines Industrial Water Laboratory, who edited and rewrote the manuscript, is very much appreciated.

Special recognition is given to the late John Bimestefer, Jr., chief engineer of the Sparrows Point plant, for his vision and determination to foster the project to its successful conclusion.

All photographs appearing in this publication were made available through the courtesy of the Bethlehem Steel Co.

STATEMENT OF THE PROBLEM

Oil that accumulates on the surface of streams and other bodies of water presents a serious pollution problem. It restricts the absorption of oxygen by water; suffocates plant, fish, and other marine life by intimately coating exposed surface areas; becomes a serious fire hazard to shoreline installations, boats, and equipment used on or near the water; creates nuisance odor conditions; and restricts most local recreational activities in the contaminated areas.

When oil slicks were reported in inlets and coves of stream and harbor areas in the vicinity of the Sparrows Point plant, an immediate investigation was instituted by the Bethlehem Steel Co. to identify the material. A visual survey of the contaminated area showed the polluting agent to be either sewage or animal and vegetable oils, used by the steel industry for cold reduction of steel plate. All were considered; they have similar characteristics in appearance, taste, and odor, and all deplete the oxygen supply.

The Bethlehem Steel Co.'s interest in possible sewage pollution came from its use of effluent (industrial water) from the Baltimore City Sewage Disposal Plant that supplies the Sparrows Point plant. The plant uses large quantities

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of water, primarily for cooling purposes, in making steel. After use at the plant, the water is discharged from numerous outlets into Humphrey Creek, which discharges into Bear Creek.

The Bethlehem Steel Co. had a second interest in identifying the stream-polluting material. Animal and vegetable oils were used as rolling-mill oils in the cold-reduction rolling mills. Routine examinations of the cooling water being discharged into Humphrey Creek had at no time shown serious concentrations of materials that might bring about stream pollution. The concentration of animal and vegetable oils in the discharged water was never more than 8 p.p.m. Nevertheless, the contaminating material was identified as animal and vegetable oils. Apparently, the oil coagulated and accumulated in quiescent areas of the streams.

ROLLING-MILL OILS FOR COLD REDUCTION OF SHEET STEEL

The sheet steel that is needed for products of modern civilization, such as automobile bodies, domestic appliances, metal food containers, etc., is first formed in a hot-strip mill. It is made into sheets less than 0.23 inch thick by passing hot slab steel through a tandem of rolls that gradually reduce its size to the final product. Some of the scale, oxides of iron formed on the hot steel during this processing is removed by scale breakers and high-pressure water sprays directed on the surfaces of the sheet. The final cleaning and scale-removal operation for these hot-rolled steel sheets is to transport them through a hot, dilute sulfuric acid bath. This procedure is known as pickling. The sheets are than oiled to prevent rusting. For the final fabrication they are reduced in thickness by passing them through a tandem of rolls, known as a cold-reduction rolling mill, at high speeds.

To facilitate the steel's passage through the cold-reduction system of rolls, and to assure a fine-textured uniform product, a mixture of oil and water is continuously sprayed upon the sheet surfaces. Water is used to control the temperature of the steel, since a considerable amount of heat is produced by the rolling action, and as a vehicle for distributing the oil. The oil spreads over the surface to insure equal pressure on all areas of contact between the rolls and the sheet.

Palm oil is normally used for the manufacture of tinplate, because of its excellent bearing properties. It has a specific gravity of 0.93 and is a wax-like solid at room temperatures. The chief constituents of the oil are the triglycerides of the long-chain fatty acids - palmitic, lauric, oleic, and stearic. A small amount of free fatty acid is desirable in rolling-mill oil to assure proper attachment to the steel surface.

Sperm oil is occasionally substituted for palm oil for the manufacture of light-gage cold-rolled steel. Mineral and synthetic detergent oils are often utilized as rolling-mill oils for the production of heavy-gage cold-rolled steel.

The production of cold-rolled sheet steel at the Sparrows Point plant is accomplished in four cold-reducing rolling mills. These mills are identified as follows:

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1. A 42-inch dual unit, made up of two five-stand tandem rolling mills, processes steel sheet for tinplate. These mills have rated maximum speeds of 1,600 and 1,750 f.p.m. and utilize about 2,500 g.p.m. of cooling water mixed small amounts of palm oil.

2. A 56-inch mill, a five-stand tandem rolling mill with a maximum speed of 4,200 f.p.m., is used to process steel for tinplate and other light gages. This mill utilizes about 2,000 g.p.m. of cooling water mixed with small, measured amounts of palm oil during its operation.

3. The largest of the four mills is a 66-inch, four-stand tandem rolling mill processing heavier cold-rolled sheets at a maximum rated speed of 3,000 f.p.m. This mill requires about 1,500 g.p.m. of cooling water, mixed with mineral oil, synthetic detergent plus some palm oil, for full-scale operation.

The measured rolling-mill oil used with the cooling water for each of the cold-reducing rolling mills will produce an oil-suspension concentration within the ranges of 500 to 700 p.p.m.

To collect the rolling-mill-oil cooling-water mixture and remove it from the plant, a catch pit (and alternate) with pumps was installed in the basement area under each cold-reduction mill. After the water cascaded from the sheet, it drained into the appropriate pit and was pumped into Humphrey Creek. There was one pit (and alternate) with pumps for the two 42-inch mills and one pit (and alternate) with pumps for both 56- and 66-inch mills. To maintain continuous operation of the rolling mills the water drainage was switched each week between pits and alternates, as the accumulated dirt-scale oil sludge was removed. The sludge was dug out of the idle pit and carted away, to be burned in an outlying area of the company property.

OIL SALVAGE BY SIMPLE GRAVITY SEPARATION

A preliminary attempt to stop the rolling-mill-oil discharge into Humphrey Creek was made by recirculating the oil-water mixture from the basement pit back over the sheet being rolled. This was unsatisfactory, because:

1. The temperature of the recirculated cooling water rose to 123° F. within 3 hours.

2. The recirculated water produced a brittle steel sheet with dirty, wavy surfaces.

3. The recirculated water, when heated, gave off very offensive odors.

The next step toward oil salvage was to install simple skimming devices on each pit below the 42- and 56-inch mills. As the oil separated from the water and floated to the surface, it was skimmed into a container at one end of a pit and pumped into a series of holding tanks. In these tanks the oil was progressively separated from its impurities by a sequence of heating, settling, and decanting operations. The net recovery of oil by this treatment was about 15 percent of the total rolling-mill oil used. The recovered oil

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was pumped to a blending tank, and mixed with equal quantities of new palm oil for later use on pickled steel to prevent rusting.

The quality of the recovered oil by heat treatment, as well as the efficiency of the process, was low. To improve these methods, the Bethlehem Steel Co. employed Palm Oil Recovery, Inc., to install and operate oil-refining equipment. The new process was a proprietary, economic method that produced about twice as much oil from the skimmed sludge as compared to heat-treatment procedure, and the quality of oil was better. The more highly refined oil produced by Palm Oil Recovery, Inc., was good enough for blending with virgin palm oil and reuse as a rolling-mill oil in the cold-reduction rolling mills.

The next progressive step in the oil-salvage research was to investigate the effect of increased retention time of the rolling-mill-oil cooling-water effluent toward improving oil separation. The maximum retention time in a catch pit, considering the pit size and the location of the inlet and outlet, was about 8 minutes. This was known to be insufficient for maximum oil salvage, and the following tests were made:

1. To increase retention time without interfering with production schedules of the mill, a small, controlled flow of the oil-contaminated cooling water was diverted from the operating catch pit under the 56-inch mill to the alternate pit. Tables 1 and 2 compare oil salvage at a normal 8-minute retention time with the effect of longer periods, up to 107 minutes.

TABLE 1. - Characteristics of cooling water, flow at 1,500 g.p.m. to catch pit, 56-inch mill, water retention time in pit 8 minutes

	Industrial water used in plant	Water entering pit	Water leaving pit
Specific gravity	1.0	(1/)	1.001
Iron, p.p.m.	.6	110.0	12.0
Solids, Do.	14.0	1183.0	210.0
Oil, palm, Do.	.0	414.0	340.0
pH	6.5	7.1	7.3
Surface tension, (dynes per cm. at 70° F.)	72.5	(1/)	63.5

1/ No analysis made.

TABLE 2. - Effect of increased retention time on oil removal from waste water; alternate pit for 56-inch mill

Water inlet, g.p.m.	Retention time, minutes	Velocity through pit, f.p.m.	Oil in outlet water, p.p.m.	Type of oil
1142	10.3	2.12	182	Palm.
818	14.2	1.54	170	Do.
540	21.8	1.00	224	Do.
420	28.1	.78	176	Do.
110	107.0	.20	214	Do.
1480	8.0	2.75	936	Sperm.
540	21.8	1.00	865	Do.
300	39.2	.56	588	Do.

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As shown in table 2, water retention time had comparatively little effect upon the overall recovery of oil by sedimentation and simple skimming. The temperature of the waste water entering the pit was 90° F. for all tests. The only variation from usual operation during the experimentation was the use of smaller amounts of palm oil and larger amounts of sperm oil.

2. A sample of the waste water entering the pit under the 56-inch mill was taken in a 600-ml. beaker. Visual observation was made of this sample with the following results:

(a) After 15 minutes one-fourth inch of dirty sludge had collected at the surface of the liquid, some solid matter had settled to the bottom of the sample, and the intermediate layer had become partly clarified to a light-gray, translucent liquid.

(b) After 24 hours no additional changes had taken place in the amount of dirty sludge on the surface, the solids settled to the bottom.

(c) After 7 days the sample color had become an overall black, and the odor was obnoxious. There appeared to be about the same amount of oil sludge on the surface that was observed previously. The drastic color and odor changes probably are related to the use of reclaimed sewage as industrial water.

3. A drop of fresh waste water was viewed through a microscope. It was discovered that the oil was in globules, averaging approximately 0.0001 inch in diameter. A photomicrograph of the sample is reproduced in figure 1. The large dark masses shown in the picture are occlusions of dirt in oil, and the side of the smallest square measures 0.002 inch.

4. Another sample of the waste water was centrifuged for 30 minutes at 3,000 r.p.m. and a drop viewed through the microscope. The only difference observed between the centrifuged drop and the one photographed for figure 1 was the absence of dirt in the centrifuged sample. The oil globules were of the same size and in the same relative distribution pattern.

OIL SALVAGE BY SIMPLE AERATION

Since the suspended droplets of waste rolling-mill oil were not buoyant enough to rise to the surface of the water without assistance, an attempt was made to combine or coagulate the oil particles by simple aeration. The equipment designed and constructed for the aeration experiment included a tank (fig. 2) equipped with an aeration device (fig. 4) and the necessary piping (figs. 3, 4, and 5). The complete apparatus was installed near the catch pit for the 56-inch mill. The aeration device was a vertical, centrifugal pump in an open casing, submerged about 24 inches below the liquid level. The waste water to be processed entered the pump just above the impeller, and the air was aspirated in at the impeller level. The action started when the pump impeller broke up in the air stream into small bubbles that were thoroughly mixed with the incoming waste water. The agitating action continued as the water-air mixture was pumped through a vertical pipe, connected to the pump discharge,

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at the bottom of the tank. The mixture then rose to the surface of the liquid in the tank; each air bubble carried with it a film of oil, dirt, and steel

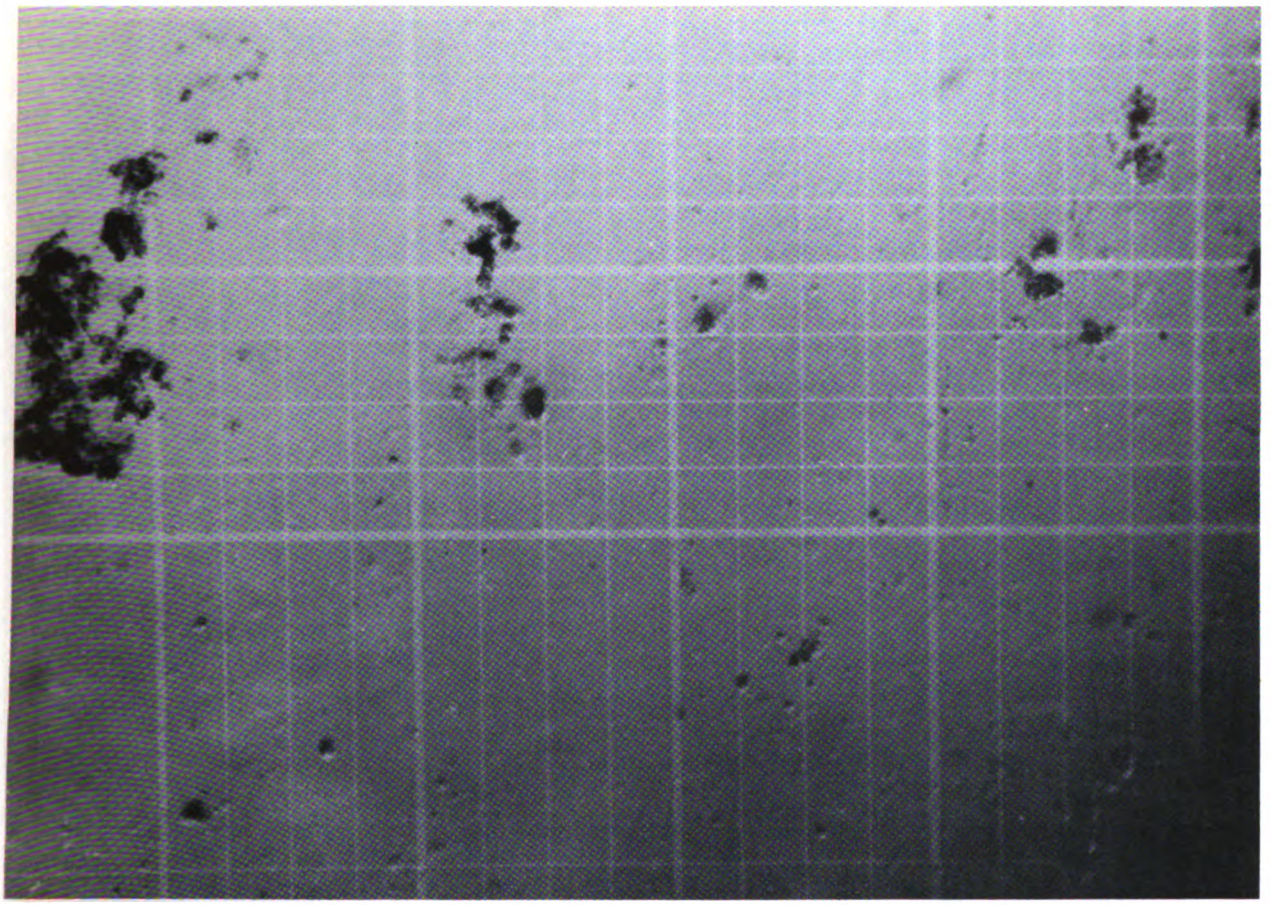

FIGURE 1. - Photomicrograph of Cold-Reduction-Mill Waste Water Taken From Catch Pit in Basement Under 56-Inch Mill. (Sides of minor squares represent 0.002 inch.)

particles to form a blanket of oil sludge over the surface. The floating sludge was removed with a simple skimming device and transferred to a container attached to the tank.

The object of pumping the air-water mixture to the bottom of the tank was to create a more positive suction action at the pump inlet and to agitate the incoming waste water thoroughly, by turbulence, to prevent prior sedimentation. An inherent defect of the equipment resulted in dilution of the feed stock and incomplete impeller-air action. A considerable proportion of the waste water was not sucked into the pump and the amount of water containing oil in suspension that bypassed the pump increased as the flow rate to the tank was raised. Also, at rates above 500 g.p.m. agitation of the liquid entering the tank became quite violent, even to the point of eliminating the floating sludge blanket. In an effort to control some of this violent turbulence, the pump speed was reduced from 880 to 645 r.p.m., and one-half of the test runs were made at this speed. Reduction of speed was ineffective, and the violent agitation

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continued at high flow rates. The apparent solution of excess agitation was lower input rates that permitted longer retention of the waste water in the

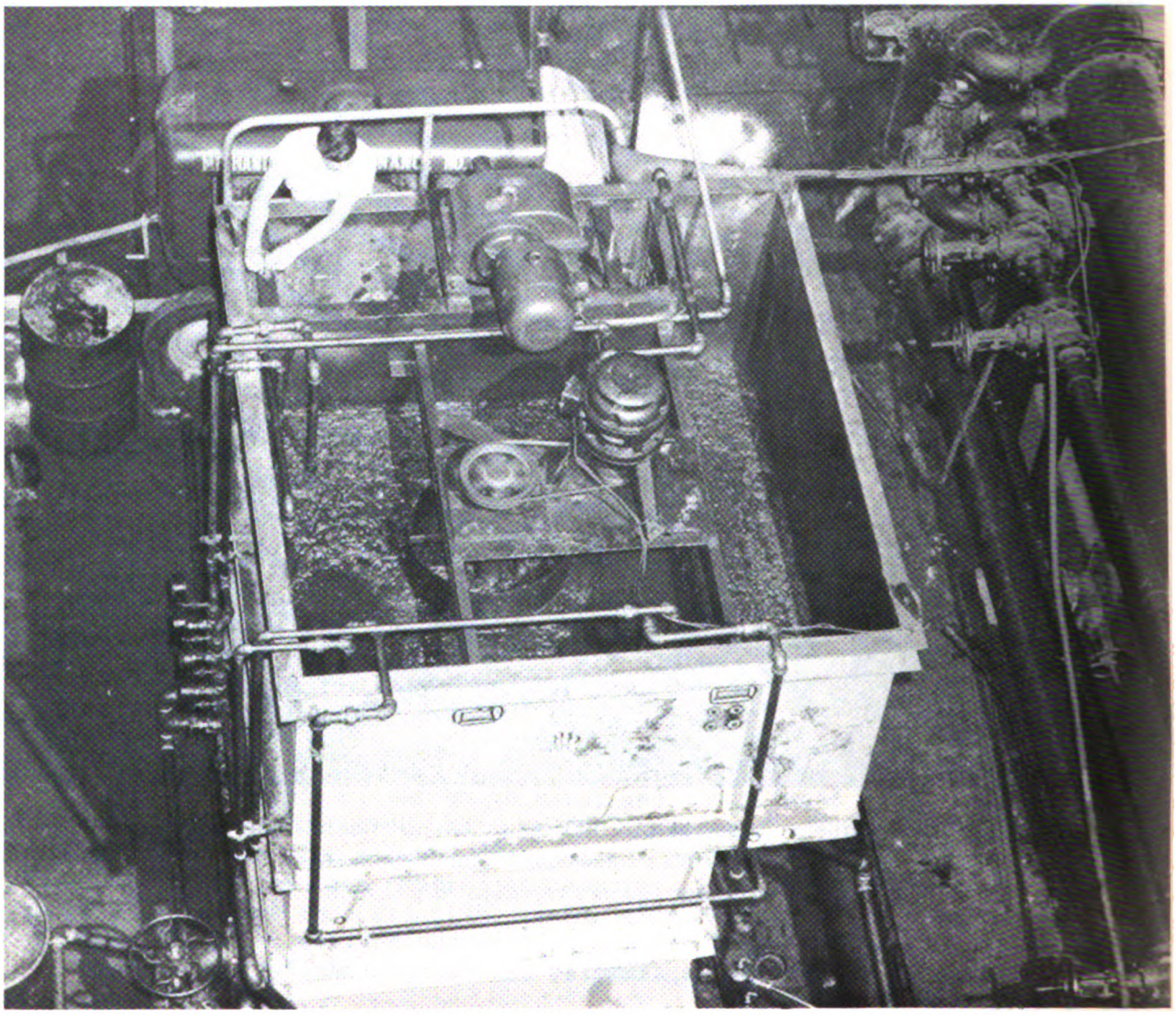

FIGURE 2. - Tank Used to Study Oil Removal by Aeration of Cold-Reduction-Mill Waste Water From the 56-Inch Mill. (See fig. 4 for details of tank interior.)

aeration tank. Results of varying the feed rate to the simple aeration tank are shown in table 3. Each test was continued for 1 hour before a sample was taken. The temperature of the waste water was 90° F., and aeration resulted in no significant change.

In an attempt to correct some of the basic deficiencies of design, baffles were added to the aeration tank, and an air header was substituted for the pump. Figure 6 shows the improved equipment. One run was made with this apparatus at a feedwater flow rate of 255 g.p.m. and a retention time of 8.5

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minutes. The air pressure was 2.5 p.s.i.g. Mineral oil was then being used as the rolling-mill oil on the mill. The oil content of the waste water was

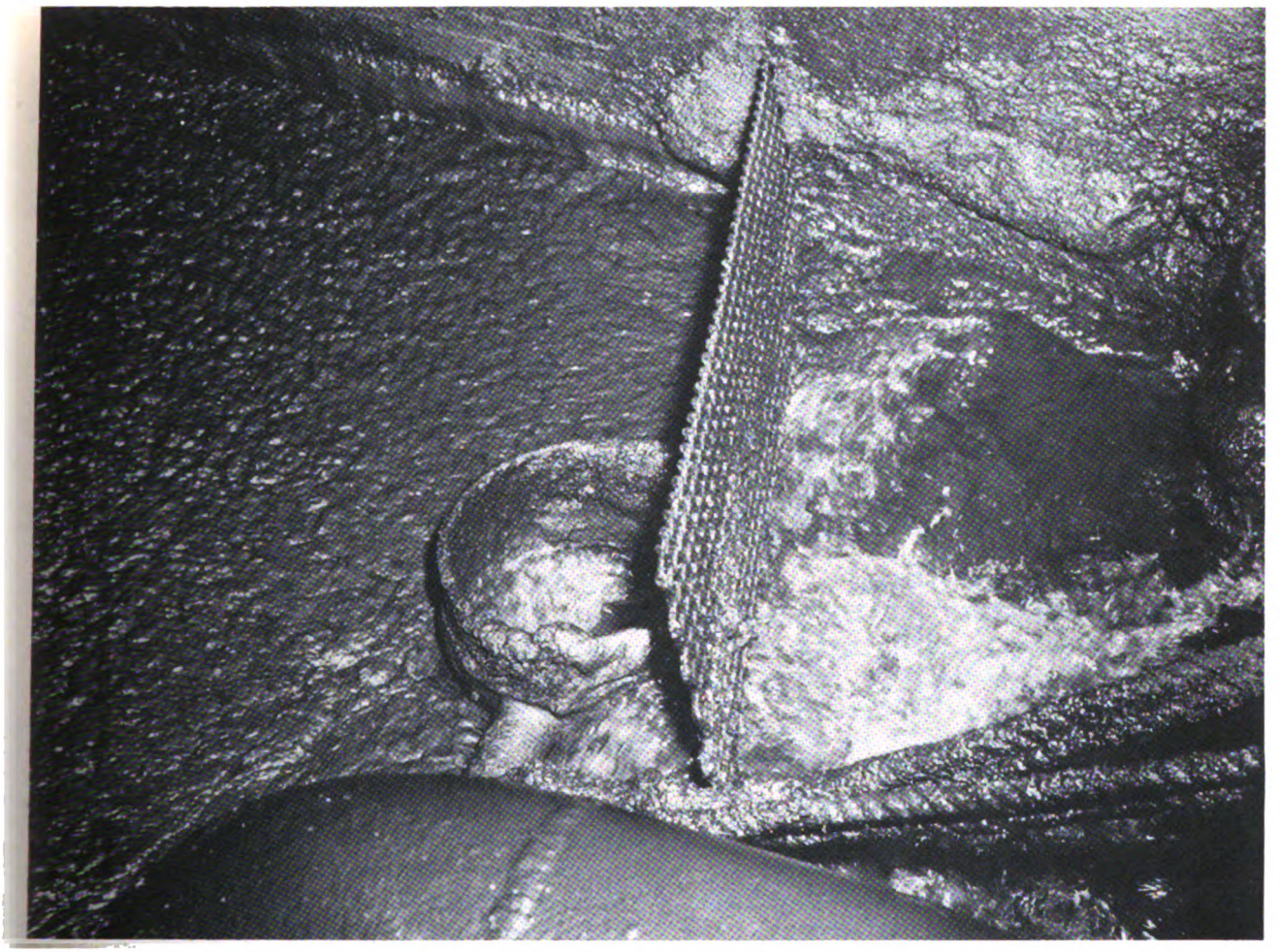

FIGURE 3. - Suction Arrangement for Pump Used to Remove Waste Water From Catch Pit Under 56-Inch Mill. (See fig. 5 for details of construction.)

486 p.p.m.; after aeration the oil concentration was 154 p.p.m. The relatively minor changes in the equipment thus produced definite improvement in the aeration process. There was a marked decrease in surface turbulence and 68-percent oil recovery was much better than the results of previous tests.

OIL SALVAGE BY FLOTATION

Flotation is a process of selective separation of minerals in ores and chemical compounds in pulps or slurries by causing certain grains or compounds to rise to the surface in a cell or tank by the action of bubbles of air. The grains or compounds that rise to the surface are caught in a froth formed on the surface of the cell or tank and are removed with this froth. Reagents that create a film or induce a froth are commonly used to assist in the flotation process.

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The simple aeration discussed in the preceding section approached flotation in principle. The encouraging results led the Bethlehem Steel Co., with technical assistance from the Bureau of Mines, to conduct a series of laboratory and pilot plant studies on additional advantages to be achieved through flotation. It was thought that proper equipment, with or without reagents, would provide an efficient, economical method for salvage of waste-rolling-mill oils from the effluent cooling eater of the cold-reduction rolling mills.

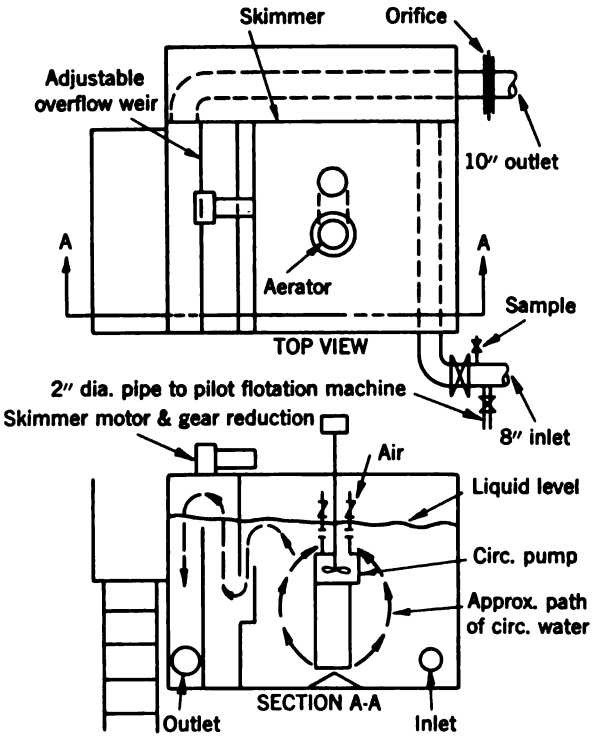

FIGURE 4. - Details of Interior of Tank Shown in Figure 2.

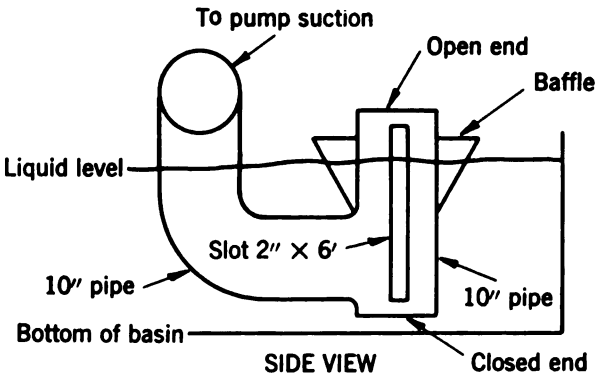

FIGURE 5. - Details of Suction Arrangement Shown in Figure 3.

Laboratory Flotation Tests

The preliminary laboratory work on flotation of oil from waste water was conducted at the Eastern Experiment Station of the Bureau of Mines, College Park, Md. Waste water containing 407 p.p.m. of palm oil in suspension was utilized in 1,000-ml. batches for the series of tests summarized in table 4.

The flotation experiments were carried out in a 1,000-ml. laboratory-size flotation cell, operated for 4 minutes per batch with air injected under slight pressure just below the impeller installed in the cell. The froth forming on the cell surface was manually skimmed off as dry as possible. To facilitate removal of this froth 135 ml. of tap water was added during the 4-minute flotation period of each test. The chemical reagents used are acids or bases to control the pH, an important factor in many types of flotation, and conditioners to increase efficiency by acting as collectors, frothers, depressors, or deflocculators. Where pretreatment of a sample is noted in the table, the conditioning was effected in the cell by agitating the reagent and waste water with the impeller before air was added. This preliminary conditioning was carried out for 5 minutes with the coal or coke and for 2 minutes with the lime and copperas.

To supplement the laboratory flotation experiments, several filtration tests were made on separate 1,000-ml. samples of waste water. The high efficiency of oil removal accomplished by filtration indicated that most of the

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oil droplets were larger than the pores in the filtering medium. However, further experimenting with filtration procedures was discontinued because oil recovery from the contaminating solids was not considered economically feasible.

TABLE 3. - Efficiency of simple aeration, using equipment shown in figures 2, 3, and 4

Run	Water inlet, g.p.m.	Retention time, minutes	Oil used	Pump, r.p.m.	Oil concentration, p.p.m.		Efficiency, percent
					Inlet	Outlet	
1	300	7.2	Palm	880	613	266	57
2	360	6.0	do.	880	554	291	47
3	535	4.0	Sperm	880	482	321	33
4	630	3.4	do.	880	470	392	16
5	728	3.0	do.	880	411	345	16
6	600	3.6	Palm	645	507	419	17
7	480	4.5	Sperm	645	686	504	27
8	305	7.0	do.	645	531	297	44
9	245	8.8	do.	645	398	226	43
10	155	13.9	do.	645	702	353	50

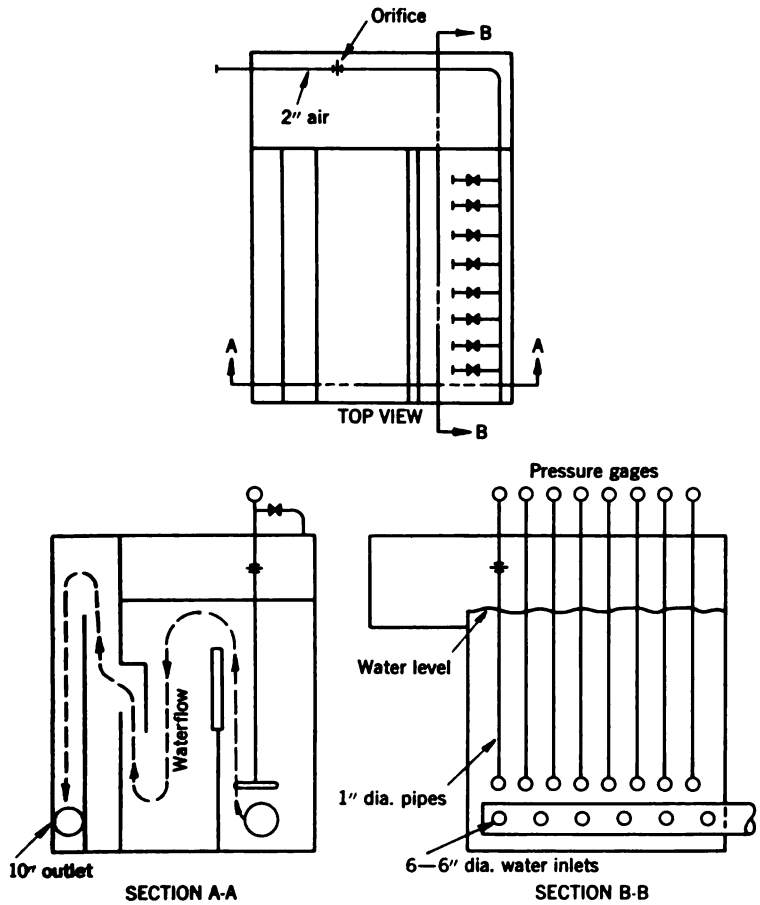

FIGURE 6. - Modified Apparatus for Aerating Cold-Reduction-Mill Waste Water From 56-Inch Mill.

Analysis of the results from the laboratory flotation tests, table 4, showed the small-bubble flotation without the use of reagents to be the most economical and most efficient procedure, therefore, the logical method for further study. In the laboratory, this method removed up to 89 percent of the suspended palm oil from the waste water. This efficiency could be increased through the use of chemicals, but the increase would not compensate for the increased costs. For example, water economy would require the removal of reagent conditioners, since one objective was to reuse the water as a coolant at the cold-reduction mill.

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TABLE 4. - Bureau of Mines laboratory flotation experiments (1,000 ml. batches of waste water containing 407 p.p.m. of palm oil in suspension at a pH of 6.5)

Test	Reagent	Treatment[1/]	Filtration medium[2/]	Results	
				pH	Oil, p.p.m.
1		Flotation		7.0	42.3
2		Filtration	No. 42 paper	7.1	51.8
3		1st Flotation			
		2d Flotation		8.3	35.3
4	2g.NaOH	Flotation		11.8	26.0
5	2g.NaOH	do.		11.8	37.0
6	1.6 ml.-66°B. H_2SO_4	do.		1.6	39.6
7	1.6 ml.-66°B. H_2SO_4	do.		1.6	48.0
8		Filtration	Coal	6.7	11.8
9		do.	Limestone	6.8	12.8
10	50g.-20-mesh coke	Flotation			
		Filtration	No. 42 paper	(3)	(3)
11	10g.-10-mesh coke	Flotation		(3)	(3)
12	10g.-20-,+65-mesh coke & 2 dr. pine oil	do.		6.6	24.6
13	10g.-20-,+65-mesh coke & 2 dr. pine oil	do.		7.1	24.3
14	10g.-35-mesh coal	do.		6.9	34.0
15	3g. lime and 1g. copperas	do.		12.1	73.6
16	10g.-35-mesh coal	do.		8.6	51.8
17	0.3g. lime & 1g. copperas	do.		10.2	46.6
18	0.3g. lime & 1g. copperas	do.			
		Filtration	Coal	8.9	3.0
19	10g.-20-,+35-mesh coal, washed after sizing	Flotation			
		Filtration	Coal	7.9	8.4

1/ Unless otherwise stated, all work was carried out at room temperature.
2/ Filtration was through a No. 42 filter paper, or through a 1-5/8-inch I.D. cylinder filled with 10 inches of -4-,+14-mesh particles below 2 inches of +4 particles.
3/ No reading made.

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Comments on laboratory tests:

Test 2. Filtration of 1,000 ml. was not complete after 45 minutes.

Test 3. Tailings of first flotation were heated from room temperature to 55° C. and then floated a second time. Temperature of tailings at the end of second flotation was 51.5° C.

Test 5. Sample and reagent were first heated together to 55° C. and then floated.

Test 7. Sample and reagent were first heated together to 55° C. and then floated.

Test 8. Filtration time was 11 minutes, 12 seconds.

Test 9. Filtration time was 11 minutes, 45 seconds.

Test 10. Tailings were black with coke. Filtrate was dark gray.

Test 11. Tailings were light gray, with coke.

Test 12. The sequence was pretreatment with coke, addition of pine oil, and flotation.

Test 13. Sample and coke were heated together to 55° C., pine oil was then added, and the sample was floated.

Test 14. Tailings were dark gray with coal. The sample frothed more during flotation than did the one conditioned with coke.

Test 15. Considerable froth was formed, and about 260 ml. of liquid was unavoidably skimmed off with the froth. The froth was brown. A brown floc settled out after flotation.

Test 16. Less froth was formed by this sample than by sample 14. Tailings were light gray with coal.

Test 17. Much less froth was formed by this sample than by sample 15. About 50 ml. of liquid was unavoidably skimmed off with the brown froth. Less brown floc settled out than with sample 15.

Test 18. Tailings were filtered. Filtrate was slightly colored yellow by a floc that passed through coal mass. Filtration time was 10 minutes, 10 seconds.

Test 19. Tailings were filtered. Filtrate was slightly gray due to dispersed coal.

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Pilot Plant Flotation Tests

Based on the findings from the laboratory tests, small-bubble flotation without reagents was selected for pilot-plant study at the Sparrows Point plant. A six-cell, impeller-type 12-gallon-capacity flotation machine was furnished by the Bureau of Mines to continue the experiments at the steel plant. The machine was placed in operation at the 56-inch cold-reduction mill with a feed rate of approximately 2 gallons per minute of waste water containing 64 to 121 p.p.m. of palm oil in suspension. This feed, at about 90° F., was supplied to the machine by a small-capacity pump with a suction point about 4 feet below the liquid surface in the catch pit. The effluent water, after flotation, contained 28 to 59 p.p.m. of oil. The low feed rate and the location of the intake to the small pump were responsible for a waste-water feed that contained no solids and a lower-than-usual concentration of suspended oil. The 12-gallon-capacity flotation unit apparently was too small for effective continuous oil removal under these conditions.

The Bethlehem Steel Co., to obtain more representative pilot-plant data, installed a four-cell, impeller-type, 81-gallon-capacity flotation machine of conventional design. This machine was placed in operation at the 56-inch mill, and the feed was taken from the same pump that discharged into the large tank shown in figures 2 and 3.

This feed comprised a range of typical oil-water-solid mixtures, representative of the cooling-water rolling-oil effluent from the cold-reduction mill. A photograph of the machine in operation is shown in figure 7.

The feedwater was drawn into the first cell of the four-cell unit by the slight vacuum created by the impeller. Air was aspirated into the machine at a point just below the impeller and was broken into very small bubbles by the impeller action. Waste water and air were thoroughly mixed so that each bubble became encased by oil and occluded solid particles. These were carried to the surface of the cell as the air rose to the surface. The scum of floated sludge was skimmed continuously into a launder at the front of the machine. The partly deoiled water flowed through an aperture in the cell wall, below the water level, to a partitioned area where it rose to flow over a weir to the suction side of the second cell. The flotation of oil was repeated in each cell, and relatively clean water overflowed from the last cell to the discharge. The weir at each cell was adjusted for optimum skimming of sludge. After a small deposit of sludge built up on the cell walls and skimmers, there was no further progressive deposition of sludge in the cell. The cell floor remained relatively oil free at all times. Each sample was taken after at least 15 minutes of continuous operation.

Results from a series of tests are summarized in table 5. Unless otherwise indicated, the impellers were operated at 900 r.p.m. The incoming waste water and the discharged clean water were 90° F. All recorded analyses were made on samples of the waste water that flowed, in series, through the cells. A photomicrograph of waste water from run 2, table 5, is shown in figure 8.

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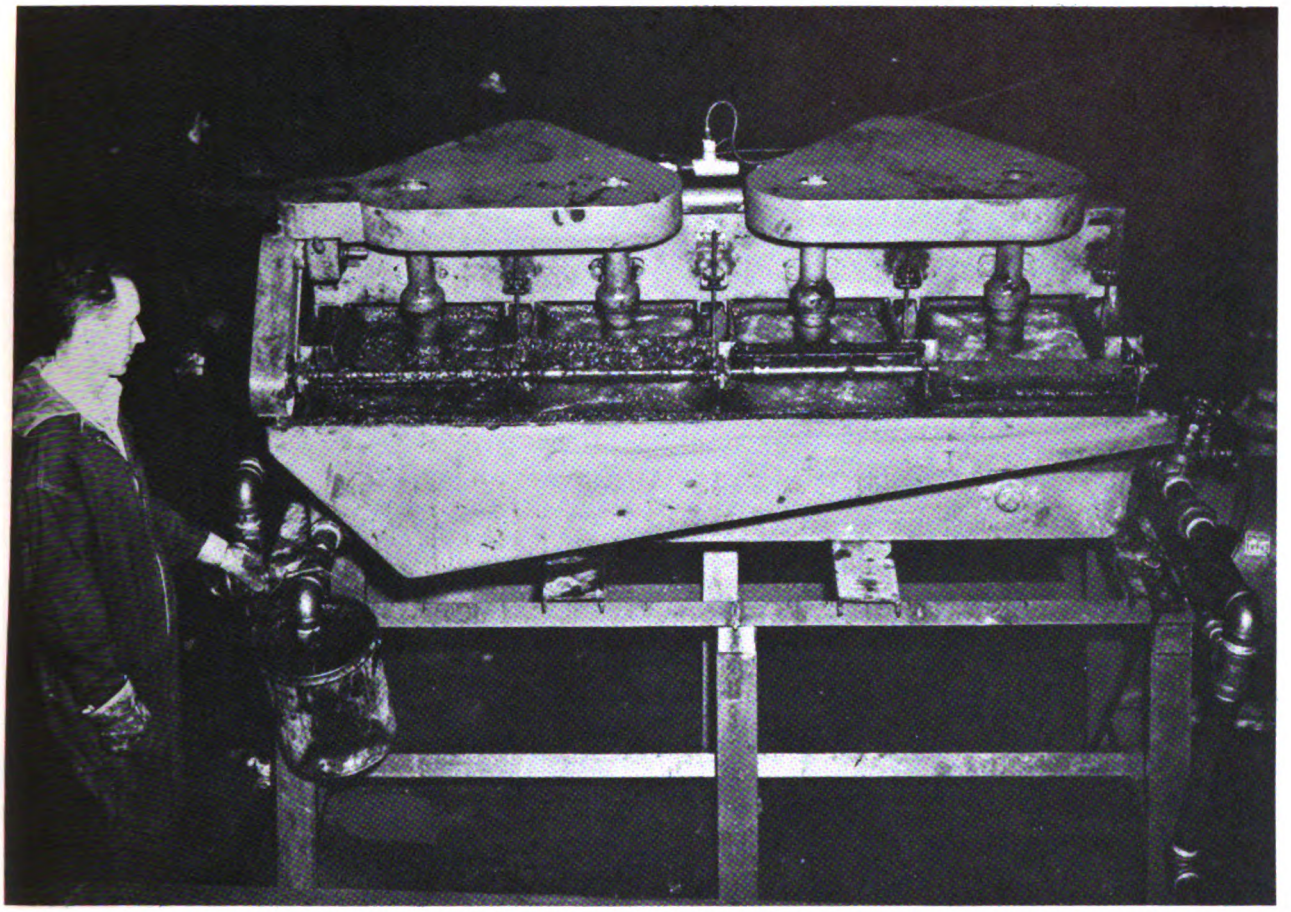

FIGURE 7. - Pilot-Plant Flotation With 81-Gallon-Capacity Machine.

Several tests made during the series represented by table 5 were not tabulated because the results were inconclusive:

1. When the impeller was operated at 600 r.p.m., the oil sludge remained in suspension and did not float to the surface.

2. In one run the feed was started into cell 2 instead of cell 1, the oil skimmings from cells 2, 3, and 4 were returned to cell 1, and the tailings from cell 1 went to cell 2. Thus, oil was removed only from the cell 1 of the machine. No samples were taken, because the discharge from cell 4, which should have been clean, was very dirty.

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TABLE 5. - Continuous flotation, using a four-cell, 81-gallon-capacity pilot plant machine on waste water effluent of 56-inch cold-reduction rolling mill

Run	Water rate, g.p.m.	Skimming, g.p.m.	Retention time, minutes	Cell no.	Oil used	Oil-content inlet, p.p.m.	Reduction outlet, p.p.m.	Percent
1 ...	14.3		5.7	4	Palm	494	71	85
2 ...	33.4		2.4	4	do.	453	65	86
3 ...	17.6		4.6	4	do.	287	51	82
4 ...	23.1		.9	1	Mineral	345	205	39
5 ...	10.0		2.0	1	do.	382	219	43
6 ...	30.0		1.4	2	do.	353	189	46
7 ...	21.2		1.9	2	do.	396	143	64
8 1/ ..	18.5	.8	4.4	4	Palm	383	64	83
9 ...	24.1	1.1	3.4	4	do.	346	30	91
10 2/ ..	29.0	1.0	2.8	4	Mineral	486	79	84
11 3 4/	29.0	1.0	2.8	4	do.	391	46	88

1/ Air was supercharged at 12 inches water pressure. For supercharging the air was blown in at the point where air is normally aspirated into the cell. Supercharging produced about as much forth on the surface as did ordinary flotation.

2/ Impellers were operated at 1,200 r.p.m. The increase from 900 to 1,200 r.p.m. produced considerably more froth on the liquid surface.

3/ Impellers were operated at 1,200 r.p.m.

4/ Air was supercharged at 11 inches water pressure.

Full Scale Flotation

The flotation equipment was designed from the data gathered in the pilot-plant testing experience. The four-cell, 81-gallon-capacity flotation machine had been operated to produce a very acceptable oil recovery - up to 91 percent of the total oils in the waste water. To project this efficiency into a production size plant, it was calculated that 10 four-cell, agitator-type, 3,000-gallon-capacity flotation machines would be required to process 6,000 g.p.m. of effluent cooling water, containing 500 to 700 p.p.m. of rolling-mill oil in suspension, from all four cold-reduction rolling mills. Because of space requirements and convenience, this equipment was located outside the steel mill adjacent to the oil-refining plant built and operated by Palm Oil Recovery, Inc. (See figs. 9 and 10.)

The auxiliary flotation equipment, including the pumps and piping, was designed for anticipated increase in water consumption for cooling purposes at the cold-reduction mills. Two 4,000-g.p.m. pumps were installed at the 56-inch mill, one at the catch pit and one at the alternate pit. The piping from these pumps to four flotation machines was 750 feet of 14-inch steel pipe and 200 feet of 16-inch cast-iron pipe, a total pumping distance of 950 feet. Two 3,000-g.p.m. pumps were installed at the 66-inch mill. These were piped to three flotation machines through 200 feet of 14-inch steel pipe and 200 feet of 16-inch cast-iron pipe.

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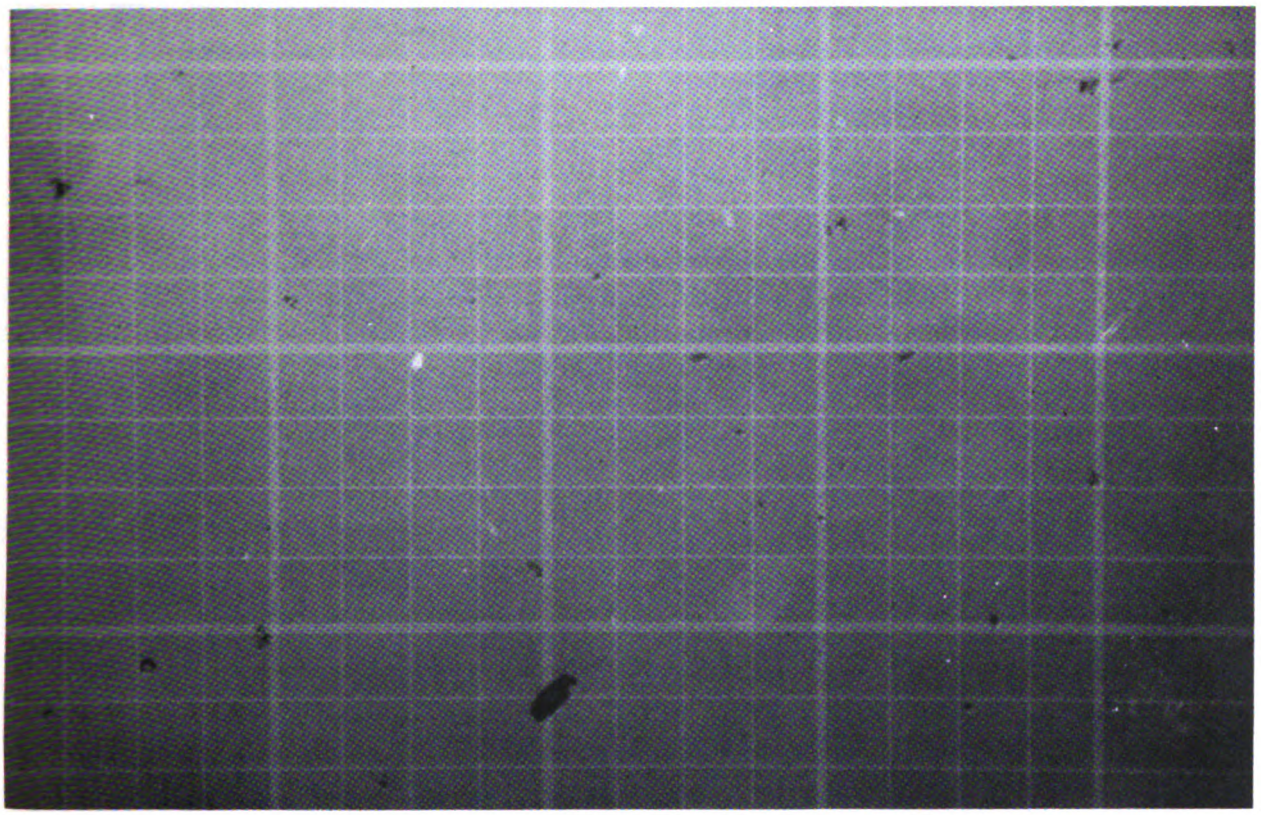

FIGURE 8. - Photomicrograph of Water Discharge From 81-Gallon-Capacity Flotation Machine, Run 2.
(Sides of minor squares represent 0.002 inch.)

The two pumps, installed at the 42-inch mills, were 2,000 g.p.m., and the piping was 800 feet of 12-inch steel pipe plus 800 feet of 12-inch cast-iron pipe.

The individual flotation machines of each rolling-mill group were tied together in parallel, with common headers, one for waste-water feed to the No. 1 cells and another for the discharge of "clean" water from the No. 4 cells to one of three surge basins of 7,500-gallon capacity. The basins were connected by a sewer, 48 inches in diameter by 70 feet in length, which emptied into a 45,000-gallon lagoon. The water left the lagoon under a baffle and entered Humphrey Creek, which flows into Bear Creek and finally into Chesapeake Bay.

The waste-water lagoon is an irregularly shaped body of water formed by building an earth dam or dike across a slight ravine at the end of the sewer outlet from the 7,500-gallon surge basins. Oil sludge that rises to the surface in the lagoon is skimmed off at the outlet and pumped to the oil-refining plant. The oil sludge, skimmed from the surface of the lagoon, contains oil from the waste water that has bypassed the flotation machines, including accidental spills and oil-refining plant residues. Water that discharges from

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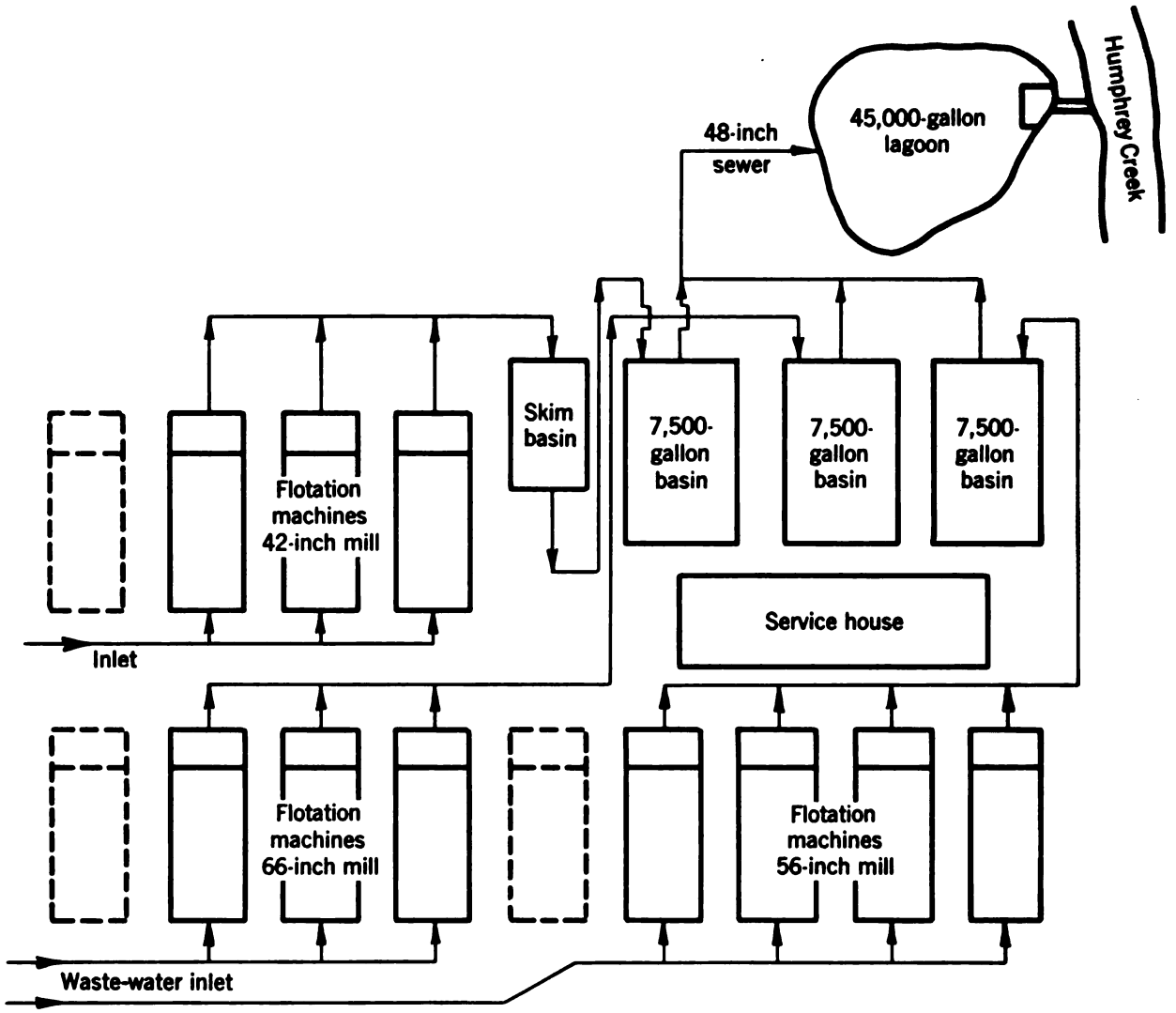

FIGURE 9. - Schematic Layout of Flotation Plant.

the lagoon to Humphrey Creek is relatively clean and contains about 20 percent of the total rolling-mill oils utilized for cold reduction of steel sheet.

The oil sludge was collected by skimming the froth, from the surface of each cell, into a launder attached to each machine. The launders of all the flotation machines sent the sludge through the common header into a holding tank. Automatic pumping then moved the sludge to the oil-refining plant operated by Palm Oil Recovery, Inc.

When the flotation units were started for production operation they were beset with the usual problems found at any startup for a new plant. Some of these difficulties and the immediate procedures used for correcting them are:

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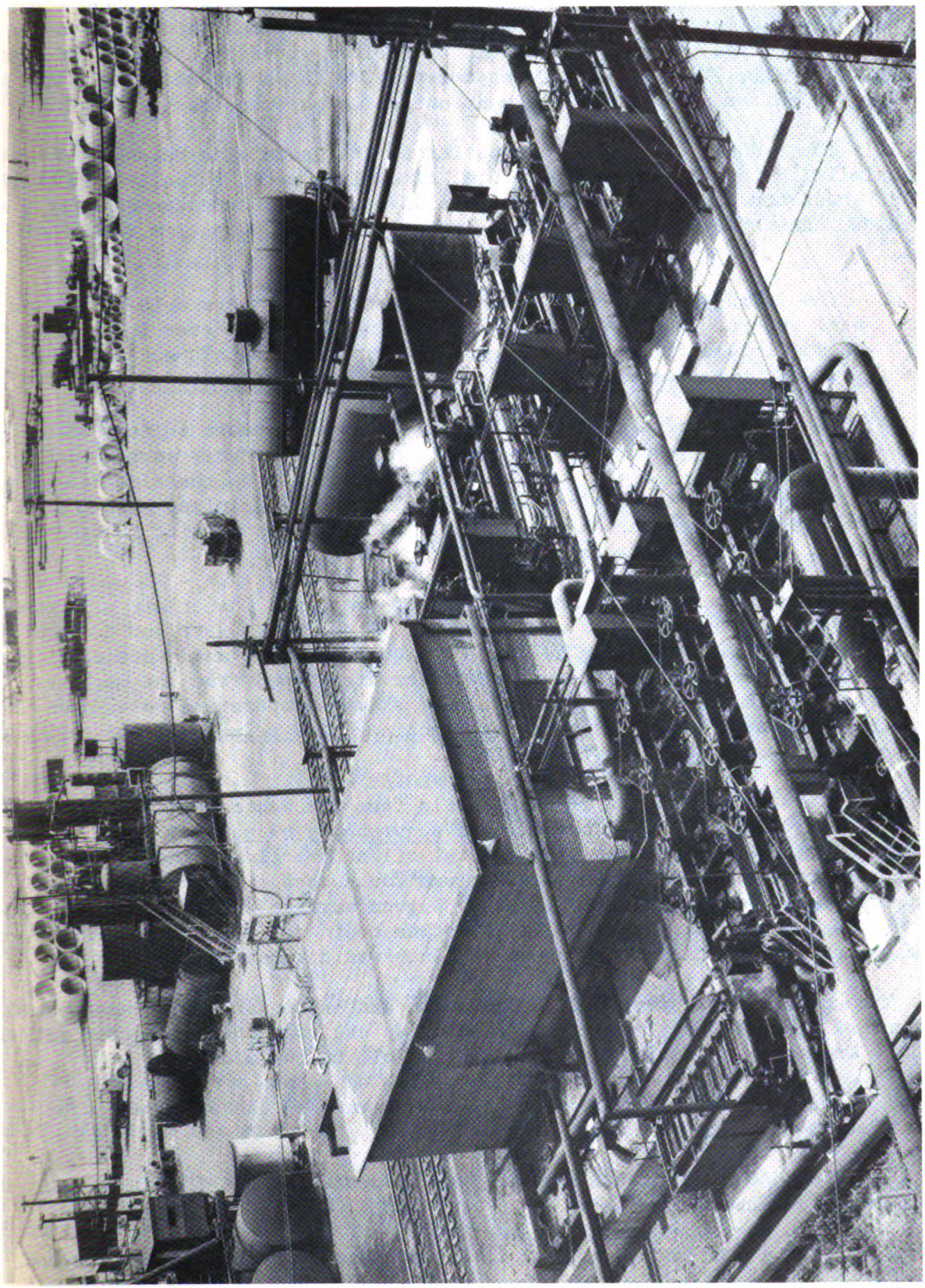

FIGURE 10. - Flotation Installation.

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1. The 4,000-g.p.m. pumps, installed at the basement catch pits for the 56-inch mill, loped on the 2,000 g.p.m. of cooling water established for normal use at this mill. This condition was corrected with an air-bleed adaptation at the pump to buffer and control the pump output to the required 2,000 g.p.m.

2. The 3,000-g.p.m. pumps, installed at the catch pits below the 66-inch mill similarly loped on the 1,500 g.p.m. of cooling water actually used on this mill. The rated capacity of the pump was adjusted to the needed capacity by an air-bleed attachment, similar to that installed on the pumps for the 56-inch mill.

3. The 2,000-g.p.m. pumps, installed at the catch pits below the 42-inch mills, were undersized since the flow of cooling water had been increased to 2,500 g.p.m. This difficulty was overcome when larger motors and impellers were installed to increase the rated capacities of the pumps.

4. The startup of a waste-water pump, after a shutdown period, would create a surge of oily water at the flotation machines. This surge usually caused overflows at the first two cells of all machines in the affected group, and the spillage was dirty, oily water. Spillage was minimized when the cell partitions were removed to make a one-cell four-impeller machine instead of the four-cell initial installation.

5. The skimming devices on the flotation machines lost their effectiveness after the cell partitions were removed. The devices were not designed to operate as a unit for cleaning so large a liquid surface, and a noticeable portion of the oil blanket was lost in the water discharged from the machines. The loss was eliminated by transferring the skimming operation to an open catch tank installed at the discharge of each machine. The skimmings were collected through launders, as previously described.

6. Flotation of the rolling-mill oils from the waste water discharged at the 66-inch rolling mill was not effective, probably because of the high percentage of detergent oil used with mineral oil at the time. There was no immediate solution to the problem, but it was found that a large percentage of this rolling-mill oil would float on the lagoon surface and could be salvaged there by skimming. Since effective flotation could not be achieved, the air-impeller action at this one group of machines was discontinued.

The combined oil salvage from flotation and lagoon skimming was about 65 percent of the total rolling-mill oils used at the four cold-reduction rolling mills. On the basis of 100-percent input of oil to the mills:

1. About 15 percent of total oil was retained on the steel sheet or otherwise lost at the mills.

2. About 50 percent of total oil was recovered by the flotation units at the 42- and 56-inch mills.

3. About 14 percent of total oil was recovered by skimming the lagoon.

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4. About 21 percent of total oil was lost from the lagoon in water discharged to Humphrey Creek.

Figure 11 indicates a typical months disposition of rolling-mill oils at Sparrows Point plant.

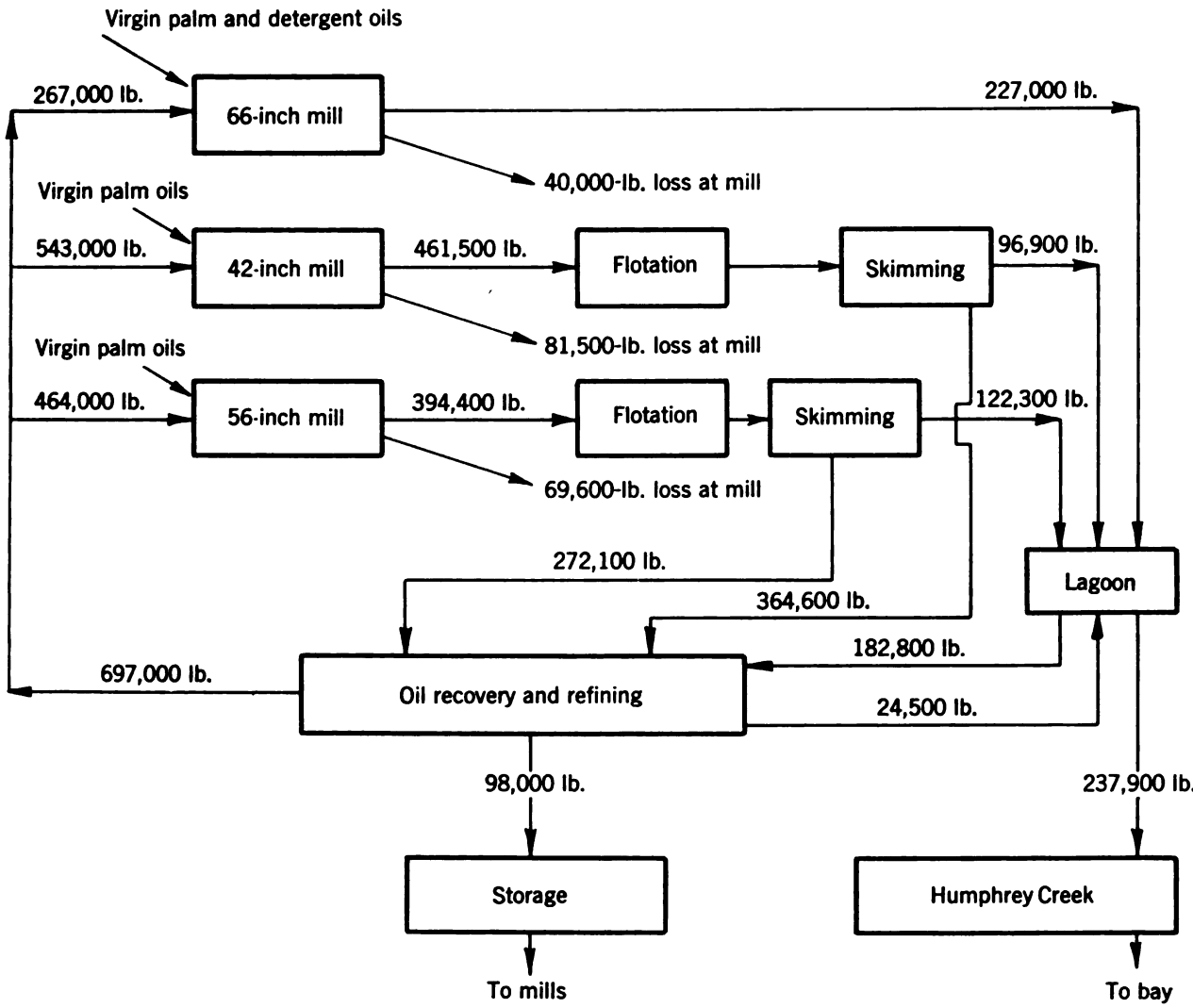

FIGURE 11. - Typical Month's Disposition of Rolling-Mill Oils at Sparrows Point Plant.

The overall efficiency, for the plant operated by Palm Oil Recovery, Inc., was high. About 98 percent of the oil in oil sludge processed in this plant was delivered to the steel mill as refined oil.

The recovery and refining of rolling-mill oils at the Sparrows Point plant has decreased the cost of this item per ton of steel processed. Oil savings within the first few years of operation were large enough to pay for the oil-recovery and refining equipment.

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